

# VLSI Handbook

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**TABLE II**  
**Aberrations at the Corners of  $2 \times 2$  mm and  $4 \times 4$  mm Exposure**  
**Fields for VS1**

	2 mm field ( $\mu\text{m}$ )	4 mm field ( $\mu\text{m}$ )
Spherical, $d_s$	0.01	0.01
Chromatic, $d_c$	0.04	0.04
Deflection, $d_{df}$	0.087	0.35
Total, no dynamic correction	0.095	0.35
Total, dynamically corrected	0.043	0.05

curvature, are proportional to  $r^2\alpha$  and  $r\alpha^2$ ; we lump them together and call their contribution to the spot  $d_{df}$ . Field distortion and some of the deflection aberrations can be reduced by adding corrections to the deflection fields. Table II shows these aberrations for the IBM VS1 machine [3].

Another source of spot broadening is the mutual Coulomb repulsion of the electrons in the beam. For total column length  $L$  this contribution is

$$d_{ee} \approx [LI/(\alpha V^{3/2})] \times 10^8 \mu\text{m}.$$

This becomes important only at large currents when small spot sizes are sought.

In the presence of aberrations, the current becomes

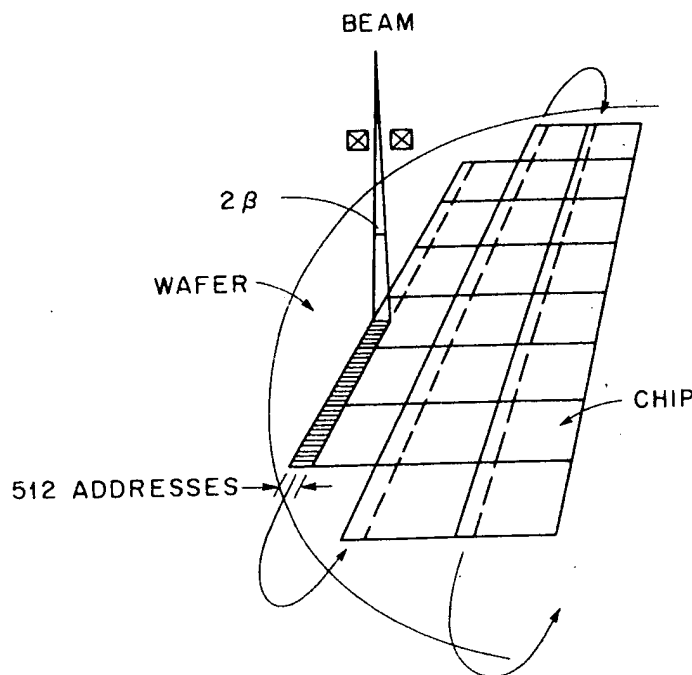
$$I = (\pi^2/4)\beta\alpha^2[d^2 - d_s^2 - d_c^2 - d_{df}^2 - \dots].$$

For a given set of aberrations, an optimum  $\alpha$  can be found that gives minimum spot size for a particular current. However, in practice, the final aperture is not changed for each current but optimized for some small spot size. Then the current and beam diameter are related by

$$I \sim (d^2 - \text{constant}).$$

## VI RASTER SCAN

In raster scan, the beam is deflected repetitively over the exposure field, as in a television raster. The beam is turned on at various points in the scan to expose the desired pattern. The EBES machine [4], developed by Bell Laboratories and available commercially from Perkin-Elmer ETEC Corp. and Extrion, uses beam deflection in one dimension. The *writing scheme* is shown in Fig. 5. The stage moves continuously in a direction perpendicular to the writing beam. The pattern data are decomposed into a number of stripes, and one stripe is written over all chips of the same type before the next stripe is begun. The stripe is 512 addresses



**Fig. 5.** Patterning with EBES. The curved arrows indicate stage motion. [From R. K. Watts, "Very Large Scale Integration, Fundamentals and Applications" (D. F. Barbe, ed.), ch. 3. Springer Verlag, New York, 1982.]

wide, an address corresponding to  $0.5\ \mu\text{m}$  or  $0.25\ \mu\text{m}$ . The pattern information comes to the blanking plates from a shift register at a rate of 20 MHz or 40 MHz. Since the total time necessary to write the 512 address scan at 20 MHz is  $31.6\ \mu\text{s}$ – $50\ \text{ns}$  per spot plus  $6\ \mu\text{s}$  for flyback, the writing time is approximately  $2\ \text{cm}^2/\text{min}$  with the  $0.5\ \mu\text{m}$  spot and  $0.6\ \text{cm}^2/\text{min}$  with the  $0.25\ \mu\text{m}$  spot. The rate is twice this at 40 MHz.

*Stage motion* is monitored by laser interferometer, and small position corrections are made by beam deflection, larger ones by drive motor speed variation. Beam position errors are checked and corrected periodically by scanning over a fiducial mark on the stage.

The EBES machine is the most widely used electron beam photomask pattern generator. The small beam deflection range  $\beta = 9\ \text{mrad}$  and the repetitive nature of the scan provide very accurate pattern placement. For writing on wafers, three or more alignment marks on the wafer are scanned to provide level-to-level registration. In raster scan the whole field is scanned. This is less efficient than vector scan but has the advantage that the polarity of the pattern is easily changed. The exposure is determined by the beam current and the (fixed)  $50\ \text{ns}$  dwell time. It is not changed during writing. Thus, corrections for proximity effect, which are easily made with vector scan, cannot be made. However, the variable scan speed of vector scan places a severe burden on the deflection system, and eddy current effects must be compensated or eliminated over a wider frequency range of the deflection system.